

SOLID STATE ELECTRICAL SWITCH

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CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

5 This patent application is related to and claims
priority of US Provisional Patent Application Serial
No. 60/130,919, filed on April 22, 1999 entitled "Solid
State Electrical Switch", Attorney Docket No. P-6043
US, also owned by the inventor of this patent
10 application.

BACKGROUND OF THE INVENTION

1. Field of the Invention

15 The present invention relates to an electrical
switch. In particular, the present invention relates
to a single-pole solid state electrical switch which
can be directly connected to the AC power lines.

2. Discussion of the Related Art

20 The basic electrical circuit includes a power
switch, and a load connected in series with the power
switch, connected across the output terminals of a
power source (e.g., an AC outlet). Typically, the
power switch is a mechanical device which makes or
breaks an electrical contact. The electrical contact
25 is made or broken by a mechanical force provided either
manually or through a magnetic field (e.g., a relay).
A manually operated conventional mechanical switch
typically toggles between "ON" (conducting) and "OFF"
(non-conducting) states by a mechanism of levers and
30 springs. Such a power switch has typically a low

a reliability and a short life-time, especially when
operating in a hostile ^{inflammable explosive} environment (e.g., high
temperature, high humidity, dusty or corrosive
atmosphere, and severe vibrations). Such a power
5 switch is susceptible to failures resulting from, ^{electrical arcing, sparks,}
mechanical wearout, corrosion, wetting, contact welding
or contact miss. Under some circumstances, a failure
of a power switch can lead to fires and other
industrial accidents, endangering property and lives.
10 To improve performance of these conventional mechanical
switches, expensive modifications and use of precious
metals are often required. Such improved switches
remain susceptible to wearing out and frequent
maintenance. Load damage can result from a defective
15 mechanical switch.

Typically, in a conventional power switch, if the
power switch is in the "ON" state when the interruption
occurs, the power switch does not reset itself to the
"OFF" state after a power interruption. Under such
20 circumstances, accidents can often occur when the
supply of power is resumed unexpectedly. For safety
reasons, in many heavy machinery, magnetic contactors
are provided to reset the power switch. Such magnetic
contactors typically are cumbersome, expensive and
25 complicated, dissipate power and create "low frequency
hum" noise. In areas where the power supply is noisy,
i.e., where there are frequent transient "snap-offs"
and "power slots", the corresponding frequent resets
required for conventional mechanical switches create
30 significant inconvenience.

In a conventional mechanical circuit breaker, the
electro-magnetic tripping or/and thermal tripping
mechanism for overcurrent protection is not designed
for frequent operations. When used with conventional
35 mechanical switches in an electrical circuit with many

branches, such a circuit breaker does not individually provide overcurrent protection to branch circuits and terminal loads. Typically, in most home or office applications, a master circuit breaker provides
5 overcurrent protection to a large number of switches, so that overcurrent in one circuit results in shutting off a large number of circuits protected by the same overcurrent protection.

For over-voltage protection, a solid state device
10 of the prior art (e.g., a solid state switch) is typically protected by a protective device which can be either a varister or a special thyristor connected in parallel with the solid state switch. In the "off" state of the solid state switch, when a substantial
15 over-voltage occurs (e.g., when the voltage across the solid state switch exceeds the "breakover" voltage of the thyristor), the protective device becomes conducting to limit the voltage drop across the solid state device, thus protecting the solid state switch
20 from damage by the over-voltage. However, if the over-voltage persists, the high current in the protective device can generate sufficient heat to irreversibly destroy the protective device over time. Thus, such an over-voltage protection scheme is expensive both
25 because of the cost of the protective device and also for the cost of replacing the protective device.

In addition, conventional switches are not practical for implementing multi-point "random" control (i.e., to allow switching "ON" or "OFF" of a piece of
30 machinery at any one of multiple locations) beyond three control points, because of the complex switch logic and the large number of wires that are required.

Because of the cost and the above disadvantages of the conventional switch, a solid state electrical
35 switch is long desired. However, until now, one

fundamental technical problem has not been solved -- a solid state electrical switch is necessarily an electronic circuit. As an electronic circuit, a DC power supply is typically required. In most integrated circuits, such a DC power supply operates at one or more lower DC supply voltages, such as 2.7v, 3.3v, 5v, or $\pm 5v$, $\pm 12v$, ..., $\pm 35v$, ... between power pins V_{CC} (or V_{DD}) and ground (or V_{SS}). Thus, unless a battery provides the supply voltages, a power supply circuit is necessary to provide the operating voltages. As a power switch, which is typically connected in series with a load, such a power supply circuit necessarily draws a current through the load, in the form of a leakage current. Such a leakage current, even though from several milliamperes to tens of milliamperes, in fact, operates the load under an "undervoltage condition." While such a switch may still be acceptable, for example, as a electronic dimmer in a lighting application, such a switch would be unacceptable, especially from a safety point of view, in applications such as fluorescent lights, AC motors, transformers or other appliances. For example, under the safety standards in virtually all countries and recognized safety organizations (e.g., the Underwriter Laboratories), a power switch which allows a leakage current in the milliampere range or higher is considered unsafe. In fact, for this reason, dimmers and electronic timers, even though connected serially with the lighting, are considered electronic appliances or loads rather than power switches. In many applications, where safety is a paramount concern, an additional conventional mechanical switch is often required to be provided in series with the electronic dimmer or timer.

In the prior art, without exception, the electronic circuit of a 2-terminal solid state switch

is connected in parallel to the load current-conducting component (e.g., between the two anodes of a triode AC switch, or TRIAC). Examples of these switches can be found, for example, in U.S. Patents 5,550,463 and
 5 5,030,890. Thus, these switches draw a significant current during the solid state switch's "off" state. From a switch current requirement point of view, any one of such 2-terminal solid state switches is not different from a solid state switch which draws a
 10 current through a third terminal directly coupled to the power source.

In addition, in the "ON" state of a solid state switch of the prior art, the voltage drop across the solid state switch (e.g., across a TRIAC), V_{on-sat} , is
 15 typically 0.8 to 1.8 volts AC. Thus, the electronic circuit of the solid state switch, which is connected in parallel with the switch terminals (i.e., across V_{on-sat}), does not receive sufficient rail-to-rail voltage for proper operation. Alternatively, for example in
 20 U.S. Patents 3,660,688 and 4,289,980, to obtain the operating voltages from the two terminals of the solid state switch, the voltage drops V_{on-sat} 's across the solid state switch can be maintained at the higher voltage ranges of 2.4-4.0 volts and 12-14 volts,
 25 respectively. However, in those solid state switches, the power dissipation can be significant. For example, if one of the solid state switches of U.S. Patents 3,660,688 and 4,289,980 is used in series with a 120 volts, 5-amp light fixture, the power dissipation in
 30 the solid state switch would reach 12-20 watts, in one case, and 60-70 watts, in the other case! To handle such severe power dissipation, not only are bulky heat sinks required, the resulting low performance and insufficient operating voltages across the load render
 35 such solid state switches impractical and undesirable.

In Figure 1 of U.S. Patent 4,703,194 to Brovelli ("Brovelli"), a 2-terminal network is disclosed. However, as in the prior art solid state switches discussed above, the main switch formed by the

5 rectifier bridge (i.e., diodes 1-4) and the silicon controlled rectifier (SCR) 6 provide an "ON" state voltage drop V_{on-sat} of 2.4-4.0 volts. Thus, as in the solid state switches discussed above, a load current of 6 amperes would result in a power dissipation of 13-24

10 watts across the solid state switch. Further, to avoid SCR 6 from switching off when the AC voltage crosses zero volts, the "ON" state of Brovelli's solid state switch is maintained by the charge stored in capacitor 7. Capacitor 7 maintains a voltage (e.g., 0.7 volts)

15 exceeding the trigger voltage of SCR 6. However, polarized capacitor 5, which Brovelli requires a 1- μ f electrolytic capacitor and performs a low-pass filtering function for the load current, cannot be used to sustain a load current exceeding one ampere. Under

20 normal "OFF"-state operation, an electrolytic capacitor working on high voltage and high ripple current conditions, or a harsh surge power line, the leakage current flowing into the load can cause a breakdown, leading to undesirable and unpredictable results.

25 Further, to ensure that the solid state switch has high sensitivity, SCR 6 must be of high sensitivity also. Typically, because of the high sensitivity required, the gain of SCR 6 is relatively low, and thus can carry only a relatively small current (e.g.,

30 TIC106D SCR is rated for a current of about 1 ampere). In order to provide a higher current, a high power component, such as a TRIAC, must be included in the solid state switch. However, such a TRIAC would short the anode and cathode terminals of SCR 6, draining

35 charge from capacitor 7 at the gate terminal of SCR 6, so that the "ON" state of SCR 6 cannot be maintained

when the input voltage crosses zero. Thus, Brovelli's design cannot be used with practical currents, and cannot be extended to handle a larger current by simply including a high power component.

5 Furthermore, Brovelli's solid state switch is turned on and off by triggering highly sensitive SCRs 6 and 9 through small currents created in touch plates 15 or 14 through resistors 8 and 11 respectively. Currently commercially available high-sensitivity SCRs 10 (e.g., Mitsubishi's CR02AM and CR03AM, and Motorola's MCR100-8 and TIC106D) all require at least 200 μ A to trigger. However, when a human body contacts a touch plate, such as touch plate 14, the impedance between the touch plate and ground through the human body can 15 often be as high as 100 ^{megohms} ~~ohms~~, thereby providing a current much lower than 200 μ A and insufficient to trigger SCR6 or SCR9 to effectuate turning Brovelli's solid state switch "ON" or "OFF". At other times, the resulting impedance between the ground and the touch 20 plate through the human body can cause a current exceeding 200 μ A, thereby causing electric shocks or raising other safety issues. For these reasons, Brovelli's solid state switch is deemed impractical.

25 SUMMARY OF THE INVENTION

The present invention provides a fully solid state 2-terminal electrical switch (referred to as the "Liu Switch"), which can be used with a single pole application (i.e., the load and the switch are coupled 30 in series to an AC power line). The Liu Switch is a static switch which does not include any mechanical or moving component, and therefore is not susceptible to wear and tear. As the Liu Switch does not include mechanical contact points, it does not create a spark,

an arc, corrosion, or mechanical noise, and can withstand operations in a hostile environment, such as a high temperature, high humidity, corrosive, dusty or intensely vibrating environment.

5 In one embodiment of the present invention, the Liu Switch, which can be directly connected in series with a load and an AC power outlet, includes (a) a semiconductor switch device controlled at a control terminal by a control signal which determines whether
10 the semiconductor switch is in a conducting or non-conducting mode; (b) a rectifier receiving an AC signal from the terminals of the semiconductor switch device during the non-conducting mode of the semiconductor switch; and (c) a control circuit including a capacitor
15 which (i) is coupled to receive the rectified signal of the rectifier during the non-conducting mode of the semiconductor switch and (ii) is discharged in response to an electrical signal from a gain circuit coupled in parallel to said capacitor.

20 In one implementation, during the non-conducting mode of the semiconductor switch, the rectified DC signal maintains the capacitor in a fully charged condition. The semiconductor switch remains in the non-conducting mode until the electrical signal which
25 causes the capacitor to discharge is received. The electrical signal which causes the capacitor to discharge can be, for example, an electrical signal associated with a button being pressed. After the capacitor is discharged, the rectified DC signal
30 provides a charging current to bring the capacitor back to a fully charged state. This charging current then provides the control signal, in the form of a trigger signal, to put the semiconductor switch into a conducting mode. The conducting semiconductor switch
35 causes the capacitor to discharge. However, at each zero-crossing of the AC signal, the semiconductor

switch device momentarily becomes non-conducting again, so as to allow the rectified DC signal to charge the capacitor. The charging current then regenerates the trigger signal to put the semiconductor switch device
5 back into the conducting mode. Thus, once the semiconductor switch device is in a conducting mode, a regenerative or feedback process provides a control signal (e.g., the trigger signal) that ensures that the semiconductor switch device remains in the conducting
10 mode.

In one implementation, the control circuit further includes a second gain circuit responsive to a second electrical signal. The second electrical signal causes a signal path to be provided between the control
15 terminal and a common ground of the control circuit, thus interrupting the feedback process by shunting the control or trigger signal to ground.

The control circuit further includes an initialization circuit having a capacitor (the "second capacitor") coupled between the control terminal and the common ground. The second capacitor has a capacitance larger than the capacitance of the capacitor of the control circuit (the "first capacitor"). A forward-biased diode couples the
20 control terminal to the second capacitor. A resistor connected in parallel with the second capacitor, in combination with the rest of the control circuit forms a circuit ("Liu's Network") with multiple time constants. In one the embodiment, Liu's Network serves
25 as both a state memory and an initialization circuit. At initialization (e.g., when power is first applied), the second capacitor of Liu's Network provides a large capacitance which absorbs the initial charging current of the first capacitor. Thus, the trigger signal that
30 places the semiconductor switch device into the conducting mode is prevented. As a result, the Liu

Switch remains in a non-conducting mode upon initialization.

Further, upon a power interruption occurring when the Liu Switch is a conducting mode, the Liu Switch
 5 remains in the conducting mode if the power resumes after a time period less than a predetermined time interval, and becomes non-conducting when the power interruption lasts longer than the predetermined time interval. Within the predetermined time interval,
 10 Liu's Network serves as a state memory which retains the conducting or non-conducting mode of the Liu Switch prior to the power interruption. In one implementation, the second capacitor is realized by an electrolytic capacitor and an unpolarized capacitor
 15 coupled in parallel.

In one implementation of the Liu Switch, the control circuit further includes a second gain circuit having a terminal which receives an external signal. Absent the external signal (e.g., a trigger signal
 20 generated by a button being pushed), the second gain circuit does not draw any current and has a high output impedance.

According to one aspect of the present invention, the Liu Switch further includes a zero-crossing
 25 detection circuit coupled to receive the rectified signal and coupled to the control terminal. The zero-crossing detection circuit prevents the control signal from being asserted except when the instantaneous magnitude of the rectified signal is below a
 30 predetermined voltage. In one implementation, the zero-crossing detection circuit includes a transistor which shorts the control terminal to common ground when the instantaneous magnitude of the rectified signal rises above the predetermined value. In one
 35 implementation, the zero-crossing detection circuit is implemented by a transistor controlled by ^{an output signal} a voltage of

a voltage divider between an output terminal of the rectifier and a common ground.

In addition, a light-emitting diode (LED) and a Zener diode connected in series with the voltage
5 divider can be included. The LED can serve as a "night light" to allow the electrical switch to be visible for certain applications.

According to another aspect of the present invention, the Liu Switch includes a current detector
10 coupled in series with the load and the semiconductor switch to provide a signal indicative of the current in the current detector. In one embodiment, the Liu Switch further includes an overcurrent protection circuit which forces the semiconductor switch into a
15 non-conducting mode when the current detector indicates a current exceeding a predetermined value. The current detector can be implemented by a transformer. In one embodiment, the overcurrent protection circuit includes temperature-sensitive components, so that the threshold
20 for overcurrent protection circuit can be self-tracking and adapted in accordance with the temperature of the environment and the temperature of the Liu Switch itself.

In one embodiment, the overcurrent protection
25 circuit includes (a) a rectifier receiving a signal indicative of the current in the current detector to provide a voltage signal which represents the current in the current detector; and (b) a threshold component which becomes conducting when the magnitude of the
30 current in the current detector exceeds a predetermined value. The threshold component can be implemented by a silicon diode, a Zener diode or a four-layer Shockley diode. The rectifier of the overcurrent protection circuit can be implemented by a Zener diode, or a diode
35 bridge. Further, the overcurrent protection circuit can include a resistor network between the rectifier

and the threshold component. This resistor network can include temperature-sensitive devices (e.g., thermistors or other thermal devices) which compensate and further fine-tune the overcurrent protection circuit's temperature response. By appropriately selecting the temperature characteristics of the temperature-sensitive devices, the tripping condition of the overcurrent protection circuit can be automatically adjusted according to the temperature of the operating environment and the temperature of the switch.

In accordance with the present invention, the Liu Switch further includes an optocoupler which controls a Liu Switch in response to any one of multiple external signals received at various points of a control bus, thus providing "multi-point random control" to the Liu Switch.

In one implementation, the Liu Switch is provided by a diode bridge and a silicon controlled rectifier (SCR). In a second implementation, the semiconductor switch is implemented by a TRIAC. In a third implementation, the semiconductor switch is implemented by antiparallel silicon controlled rectifiers. The rectifier circuit of the Liu Switch can be provided by a SCR controlled bridge rectifier. A low-pass filtering circuit can be coupled to a signal terminal of the semiconductor switch device to further protect the semiconductor switch, by absorbing any surge, shock or noise in the control input signal, thus keeping the system in steadily operations.

The touch panels can each include a metallic surface, or a metallic surface coated with a resistive material or an insulator. The touch panel can be mounted in a plane offset from a mounting plate (e.g., in a shallow depression or provided slightly protruding over the surface of the mounting plate). In one

implementation, where two touch panels (one for the "ON" function and one for the "OFF" function) are provided, the touch panels are provided different colors or provided different tactile feels.

5 According to another aspect of the present invention, the Liu Switch includes a beep circuit for providing an audible response, in the form of a "beep" sound, to the external agent when the agent contacts a touch panel. The beep sound response can be provided
10 by a Zener diode and a piezoelectric speaker connected in series across an output terminal of the rectifier of the Liu Switch and a common ground. The beep circuit can generate audible and distinguishable beep sounds to indicate which of the two touch panels is contacted.

15 In the control circuit of the Liu Switch, the various components (e.g., the gain circuits, the SCR controlled rectifier, the semiconductor switches, or the audio response circuit) are each selected such that, during the "off" state of the semiconductor
20 switch, the leakage current in each component is negligible. Consequently, negligible power is drawn by the Liu Switch during its "off" state.

Another advantage of the present invention is a state-latched control contact panels which retain the
25 "ON" or "OFF" state after contact by the external agent is broken. Based on this latch function, the Liu Switch of the present invention provides a multipoint random remote control system, including: (a) a 2-terminal Liu Switch coupled in series with a load
30 circuit between ^{two lines} ~~a phase line~~ of an AC power outlet; (b) an optocoupler coupled to the Liu Switch, the optocoupler providing a very high electrical isolation between the AC power lines and an external remote control signal bus from which the optocoupler receives
35 input signals; and (c) controllers (e.g., computers) coupled to the signal bus, each capable of asserting on

the signal bus the control signals. The Liu Switch provides an "ON /OFF" latching feature which allows random control by an unlimited number of external controllers and computers. In one implementation, the
5 signal bus include an independent external common ground to which both the "ON" signal and the "OFF" signal reference. In another implementation, separate independent external common ground references are provided for separate transmission and isolation
10 between "ON"-channel and "OFF"-channel on a four-wire external signal bus.

One aspect of the present invention provides a Liu Switch with no current leakage to the load in the "OFF"-state. Another aspect of the present invention
15 provides a Liu Switch operating under a fully dynamic run mode during the "ON"-state. The switch of the present invention operates from power received during the zero-crossing of each half-cycle of the input AC signal, thereby obviating a DC power supply. Thus,
20 unlike any electronic switch in the prior art, the Liu Switch connects in series directly to the AC standard power line.

Another advantage of the present invention provides a static overcurrent tripping circuit and an
25 automatic reset circuit in a Liu Switch. Thus, inexpensive independent overcurrent protection is provided at every load point. Independent overcurrent protection at every load point provides unsurpassed protection for property and lives.

30 Another advantage of the present invention is a universal Liu Switch capable of being directly connected to standard 120 volts, 220 volts or higher voltage AC power outlet.

According to another aspect of the present
35 invention, an initialization and power recovery reset

circuit ("Liu's Network") is provided, including: a capacitor connected in series with a diode between a control terminal and ground, and a resistor connecting in parallel with the capacitor.

5 Another advantage of the present invention provides "optional functions" in a Liu Switch. Such optional functions include providing a night light or a visible indicator on the Liu Switch. The night light or indicator function can be achieved using passive
10 fluorescent materials, such as some chemical compounds of phosphates or sulfurs.

In one embodiment, an efficient LED is incorporated into a zero-crossing detecting circuit of the Liu Switch. In that embodiment, the forward
15 voltage of the LED provides a threshold level to the zero-crossing circuit, and the LED provides a night light to illuminate the switch. In "OFF" state, the LED draws a current drawing less than 200 μ A.

Another advantage of the present invention
20 provides a Liu Switch with a programmable dynamic threshold value for overcurrent tripping protection. The threshold value adapts to temperature, loading and environment conditions, and the configuration of the switch itself. LTS character especially can be use to
25 create a smart terminals in electrical network.

The touch panels of the present invention is based on a discovery of an impedance effect related to the human body, called the "Liu's touch signal complementary effect" (referred below as the "LTS"
30 effect). The LTS effect result from the impedance properties of the human body, i.e., acting both as an impedance to ground and as an equivalent inductive signal source, over a wide range of environmental conditions. The LTS effect allows the Liu Switch to be
35 reliably switched "ON" and "OFF" over practically all

environmental conditions by a human through the touch panels.

In that embodiment, a touch panel is electrically couple to the control circuit of the Liu Switch, such
5 that when the touch panel is contacted by an external agent (e.g., a human operating the switch), an electrical path is created, and the LTS effect triggers the control circuit of Liu Switch.

According to on the aspect of the present
10 invention, the "ON" and "OFF" touch panels of the Liu Switch can be created to be different in position, color, shape, or texture, so as to ensure safety and precision operations. Such touch panels can be made from metal, resistive non-metals or conductors plated
15 with an insulating material. In a Liu Switch of the present invention, different contact durations at the touch panels are required to trigger the Liu Switch's "ON" and "OFF" operations. In some embodiments, the touch panels are designed to prevent triggering by
20 inadvertent contacts. For example, each touch panel can be provided a contact surface in a shallow depression.

In accordance with on the aspect of the present invention, the touch panels can be operated even when
25 an operator is wearing gloves. This capability can be important in certain applications which require a piece of machinery to be disabled during emergency. In accordance with another aspect of the present invention, when the first and second touch panels are
30 touched substantially simultaneously, the Liu Switch resolves to an "OFF" state, thus preventing operating a load device inadvertently.

The Liu Switch of the present can control a resistive load, an inductive load, and some special

loads, such as a fluorescent light, and can also be used to control mixed loads.

The present invention is better understood upon consideration of the detailed description below and the
5 accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a system block diagram of an electrical circuit 100, including control circuit 200
10 in solid state switch ("Liu Switch") 300 in accordance with the present invention.

Figure 2a shows equivalent circuits 250 and 250' each representing a human body in contact with a touch panel (i.e., touch panel 17 or 19).

15 Figure 2b shows characteristic curves S_a , S_b , S_c , S_d , representing respectively, the resistive (leakage), distributed capacitive, and equivalent inductive signal source components, and the sum total of the Liu's touch
20 signal complementary effect (the "LTS" effect) as a function of the impedance of the human body.

Figure 3 shows waveforms 1-4, representing (i) the voltage across load 2, when solid state switch 300 is in the "ON" state; (ii) the voltage across terminal 83 and the common ground of trigger and control circuit
25 200, when solid state switch 300 is in the "OFF" state, (iii) the voltage across load 2, when solid state switch 300 is in the "OFF" state, and (iv) the voltage
310 across terminals 01 and 02^{a2} when Liu Switch 300 is in the "ON" state.

30 Figure 4 shows on the embodiment of the present invention in a circuit 400, in which SCR controlled bridge rectifier 8 and main semiconductor switch 1 are implemented into a combined SCR-diode bridge circuit

(1,8), and first gain circuit 11 is implemented by transistor T1.

Figure 5 shows one embodiment of the present invention in circuit 500, in which SCR controlled bridge rectifier 8 and main semiconductor switch 1 are implemented into a combined SCR-diode bridge circuit (1,8), and first gain circuit 11 is implemented by transistor T11.

Figure 6a shows one embodiment of the present invention in circuit 600, in which main semiconductor switch 1 is implemented by TRIAC 601.

Figure 6b shows one embodiment of the present invention in circuit 620, in which main semiconductor switch 1 is implemented by antiparallel SCRs 602 (SCR2 and SCR3).

Figure 7a shows another embodiment of the present invention in circuit 700, in which is provided a realization of initialization circuit, includes a Liu's Network 13,15.

Figures 7b-7d show embodiments of the present invention in circuits 720, 740, and 760, each of which being a modification of circuit 700 of Figure 7a.

Figures 8a-8c show, respectively, implementations of a current limiter (i.e., current limiter 18 or 20 of Figure 1 in each of circuits 800, 810, and 820).

Figure 9a shows a overcurrent protection circuit 900, including a system block diagram of overcurrent signal processing circuit 16 of the present invention.

Figures 9b-9d show respectively circuits 910, 920 and 940 of Liu Switch 300, showing implementations of current detector 5 and overcurrent protection circuit 16.

Figures 10a and 10b illustrate micro-current zero-crossing circuits 1000 and 1050 respectively, suitable for implementing zero-crossing detection circuit 10 of Figure 1.

5 Figure 10c shows waveforms 1 and 2, being respectively the threshold voltage V_{thres} , and the impedance at the gate terminal G1 of SCR1, due to the action of transistor T4.

10 Figures 11a and 11b show implementations 1100 and 1150 of optocoupler circuits 22 and 23 of Figure 1 coupled to Liu Switch 300, in the manner discussed above with respect to Figure 1.

15 Figures 12a and 12b respectively show a 3-wire control bus 400 and a 4-wire control bus 410 which are used to provide multipoint random control of loads 2a and 2b by external equipment, through solid state switches 1200 and 1201, and to provide high isolation between the control bus, the Liu Switch and the power line.

20 Figure 13 shows a schematic diagram 1300 of one embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

25 The present invention provides a solid state switch ("Liu Switch"), which is illustrated by way of example in electrical circuit 100 of Figure 1. As shown in Figure 1, electrical circuit. Circuit 100 includes, connected in series, main semiconductor switch 1, load 2, trigger and control circuit 200, 30 electromagnetic interference (EMI) suppressers 3 and 3', fuse 4 (for short circuit current protection), current detector device 5, terminals 6 and 7 for connection to AC power outlet, and touch panels 17 and

19 for conveying external input signals to trigger and control circuit 200. In one embodiment, the Liu Switch ("Liu Switch 300") incorporates main semiconductor switch 1, current detector device 5, and trigger and control circuit 200. Together with load 2, Liu Switch 300 forms electrical circuit 100.

Trigger and control circuit 200 includes a silicon controlled rectifier (SCR) controlled bridge rectifier 8, an attenuator 9, first gain circuit 11, second gain circuit 14, current-limiters 18 and 20, initialization and power recovery circuit 15, diode gate 13, state memory and trigger circuit 12, and filter circuits 28 and 29. In one implementation of trigger and control circuit 200, for example that shown in Fig. 7a, state memory and trigger circuit 12 includes a capacitor C1 and initialization and power recovery circuit 15 includes capacitor C4.

Gain circuit 11, which is coupled to control terminal 113 and terminals 121 and 122, is designed such that, when no input signal is provided at control terminal 113, a high impedance exists between terminals 121 and 122, so that no current flows in gain circuit 11. Conversely, when an input signal is provided at terminal 113, a low impedance exists between terminals 121 and 122. Gain circuit 14, which receives a signal at control terminal 143 and controls the impedance between "executive" terminal 141 and terminal 142, can be similarly constructed. In this embodiment, however, gain circuit 14 includes additional control terminals 144 and 145, each of which can also be triggered to provide a low impedance path between terminal 141 and common ground terminal 142. Control terminal 144 is provided to allow triggering gain circuit 14 during an overcurrent condition, and one or more control terminals 145 are provided to respond to other

conditions for which Liu Switch 300 is to be turned "OFF".

Initialization and power recovery circuit 15 and diode gate 13 together provide a "Liu's Network" (described in further detail below) which includes a diode (D3), an electrolytic capacitor (C4) and a resistor R8. An unpolarized capacitor C4' can be connected in parallel to capacitor C4 to allow a faster response, as explained below. Initialization circuit 15 ensures that Liu Switch 300 is in the "OFF" state when power is first applied across its terminals, ~~and plays a part in transitioning Liu Switch 300 from the "ON" state to the "OFF" state.~~

SCR controlled bridge rectifier 8 includes a triggerable circuit, such as an SCR ("SCR1"), which becomes conducting when triggered by a control signal at terminal 84. When SCR1 conducts, main semiconductor switch 1 also conducts, thus resulting Liu Switch 300 to be triggered into a conducting mode. As explained below, once triggered into the conducting mode, Liu Switch 300 generates its own subsequent trigger signals at terminal 84 to maintain Liu Switch 300 in the conducting mode. Main semiconductor switch can be implemented, for example, by a TRIAC or SCRs.

Trigger and control circuit 200 also includes the following "optional" components: zero-crossing detector 10, coupling diode 50 (replacing jumper 60, when zero-crossing detector 10 is included), "beep" circuit 21, current detector device 5 (for overcurrent protection), overcurrent protection circuit 16, and optocoupler 22 with external control bus 400, or an optocoupler 23 with external control bus 410. These optional components allow the Liu Switch to be used in a multi-point random remote control scheme as an electrically highly isolated relay ("Liu Switch-Relay").

SCR controlled bridge rectifier 8 includes AC terminals 81 and 82, a DC output terminal 83, trigger terminal 84, executive terminal 87, and terminal 85, which is coupled to a common "ground" of control and trigger circuit 200. Resistor 86 can be provided in series with AC terminals 81 and 82. When main semiconductor switch 1 is non-conducting, terminals 81 and 82 receive an input AC signal from power terminals 01 and 02 of main semiconductor switch 1. SCR controlled bridge rectifier 8 provides a rectified signal (shown in Figure 3 as waveform 2) across terminals 83 and 85. As shown in Figure 3, the rectified signal across terminals 83 and 85 is a half-wave signal at twice the frequency of the input AC signal.

Liu Switch 300 takes advantage of an impedance effect of the present invention, referred below as "Liu's touch signal complementary effect" (or "LTS" effect), which is further explained below. In Fig. 1, Liu Switch 300 includes touch panel 17, which is electrically coupled to trigger and control circuit 200. When touch panel 17 is contacted by an external agent (e.g., a human operating the switch), an electrical path is created as the result of the LTS effect for triggering trigger and control circuit 200. The LTS effect is explained with the aid of Figures 2a and 2b.

Figure 2a shows equivalent circuits 250 and 250', each representing a human body in contact with a touch panel (i.e., touch panel 17 or 19). Under certain environmental conditions, equivalent circuit 250 is dominated by an equivalent resistance (i.e., resistor R23) representing the leakage path to ground, varying from about 30 Mega-ohms down to 100 ohms. The electrical signal intensity resulting from the LTS effect of this resistive component is shown in Figure

2b by curve S_a . Similarly, under other environmental conditions, the human body provides a medium to high of impedance (i.e., approximate from 30 Mega-ohms to 300 Mega-ohms or higher). In this range, equivalent

5 circuit 250 is dominated by equivalent capacitor C24 with distributed reactance (~~i.e., capacitance~~) X_c . The electrical signal intensity resulting from the LTS effect of this capacitive component is shown in Figure 2b as curve S_b . To properly harness this LTS effect,

10 trigger and control circuit 200 provides an anti-parallel diode connected between a common ground and an emitting junction of an input transistor of gain circuit 11.

Under even higher impedance conditions, the human

15 body can reach an impedance of more than 300 Mega-ohms or higher. At such high impedance, equivalent circuit 250 is dominated by inductive signal source AT26, providing an electrical signal from the stray electromagnetic fields of the ambience. Such electromagnetic

20 fields result from various signal sources in a wide ^{spectrum} band, from low frequency hum signals (e.g., 50(100)Hz or 60(120)Hz hum) to signals in the VHF or UHF band, and perhaps from static electricity as well, under certain conditions. Inductive signal source AT26

25 provides an electrical signal resulting from a superposition of such electromagnetic fields which can be detected by gain circuit 11 of trigger and control circuit 200. The electrical signal intensity resulting from the LTS effect is shown in Figure 2b as curve S_c .

30 The combined LTS effect of resistor R23, capacitor C24 and inductive signal source AT26 of Figure 2b is shown in Figure 2b as curve S_d . In Figure 2b, a region labeled "dull" represents the region in which the electrical intensity at panel 17 is insufficient to

35 trigger reliably trigger and control circuit 200. As shown by curve S_d , the electrical signal strength of the

combined LTS effect of equivalent circuit 250 is above the "dull" region over virtually all practical impedances. Significantly, where the resistive component (i.e., S_a) falls below into the dull region, the capacitive component (i.e., S_b) maintains curve S_a significantly above the dull region. Similarly, where both the resistive and capacitive components (i.e., curves S_a and S_b) fall into the dull region, the inductive signal source component (i.e., S_c) maintains curve S_d above the dull region. Thus, the combined LTS effect allows Liu Switch 300 to be reliably switched over practically all impedances of the human body, substantially regardless of the environmental conditions.

Equivalent circuit 250' operates in substantially the same manner as equivalent circuit 250 described, and thus description here of its operations is omitted.

The operation of Liu Switch 300 is next discussed. Initially, i.e., when Liu Switch 300 is first powered up, both capacitor C1 of state memory and capacitive triggering circuit 12 and capacitor C4 (and capacitor C4') of the initialization and power recovering reset circuit 15 are in a discharged state.

When an AC power signal is impressed across main semiconductor switch 1 and load 2 (i.e., "power-up"), terminals 81 and 82 receive the AC signal. The twin half-wave DC signal resulting from rectification by SCR controlled bridge rectifier 8 -- this half-wave DC signal has a frequency twice that of the AC signal -- appear across terminals 121 and 122. Capacitor C1 of state memory and capacitive triggering circuit 12 becomes fully charged almost immediately. ^{Initially} ~~In the first~~ ~~cycle of the AC power signal~~ after power-up, the charging current pulse is shunted through forward diode gate 13 to capacitor C4 and C4' of initialization and power recovering reset circuit 15. The voltage at

a control terminal 122 does not ^{significantly} rise to cause a signal to pass through attenuator 9 to trigger terminal 84 of SCR controlled bridge rectifier 8 to trigger semiconductor switch 1. Thus, the twin half-wave DC voltage

5 maintains capacitor C1 of state memory and capacitive triggering circuit 12 at a fully charged state. In this "OFF" state, no current flows in trigger and control circuit 200.

10 In the "OFF"-state, when a person touches touch panel 19, however, an "OFF"-state feedback effect is created. Gain circuit 14 provides a low-impedance path between terminals 141 and 142 to discharge ^{and to maintain discharged} capacitors C4 and C4' of initialization and power recovery circuit 15. Discharged capacitors C4 and C4' prevents any

15 signal at terminal 122 to trigger main semiconductor switch 1, thus main semiconductor switch 1 remains non-conducting ~~during the zero-crossings of the twin half-wave DC signal.~~ ^{As} capacitor C1 in state memory and capacitive trigger circuit 12 remains fully charged, no

20 trigger signal is propagated to the trigger terminal 84 of SCR controlled bridge rectifier 84 and hence to main semiconductor switch 1. Consequently, main semiconductor switch 1 remains stable in the "OFF" state.

25 When control and trigger circuit 200 is in the "OFF" state, first and second gain circuits 11 and 14 are both in a current cutoff state, since no signal input is received. (So long as they are not contacted, panels 17 and 19 do not provide electrical signals).

30 In addition, SCR controlled bridge rectifier 8 is in a current cutoff mode when it is not triggered. Thus, Liu Switch 300 has no leakage current to load 2 in the "OFF"-state of Liu Switch 300.

35 While in the "OFF" state, when an external agent (e.g., a human hand) touches touch panel 17, an

electrical signal is provided to Liu Switch 300 at
 input terminal 113 of first gain circuit 11, in
 accordance with the LTS effect discussed above. This
 electrical signal causes gain circuit 11 to provide a
 5 low impedance path between terminals 121 and 122 of
 state memory and capacitive triggering circuit 12. As
 a result, capacitor C1 within state memory and
 capacitive triggering circuit 12 rapidly discharges,
 and the ~~twin half-wave~~ DC signal at terminal 121 is
 10 coupled to terminal 122. ~~The discharging current of~~
~~capacitor C1 and the twin half-wave DC signal are~~
 shunted through gain circuit 11 and diode gate 13 to
 rapidly and fully charge capacitors C4 and C4' of
 initialization and reset circuit 15. ⁹⁵ Thereafter, as
 15 explained below, ^{in the next half wave} the brief charging current of
 capacitor C1 at zero crossing of the AC signal creates
 a trigger pulse ^{which continues to be} sufficient to trigger SCR controlled
 bridge rectifier 8 at trigger terminal 82 of main
 semiconductor switch 1. ⁹⁶ This trigger pulse triggers
 20 SCR1 to cause main semiconductor switch 1 to become
 conducting, thus placing Liu Switch 300 into an "ON"
 state, and providing power across load 2. In addition,
 an "ON" state feedback effect is initiated. The "ON"
 state feedback effect depends upon: (a) while SCR1 and
 25 main semiconductor switch 1 are ^{causing each other to conduct} conducting, a low
 impedance path ^{for discharging capacitor C1} is provided between terminals 121 and
 122, thus maintaining capacitor C1 in a discharged
 state; and (b) main semiconductor switch 1 remains in a
 conducting state, except at zero-crossings of the input
 30 AC signal.

At a zero-crossing, main semiconductor switch 1
 becomes non-conducting, which allows the next half-wave
 of the twin half-wave DC signal to momentarily appear
 across terminals 121 and 122, thus charging capacitor
 35 C1 almost immediately. The charging current pulse is
 coupled to terminal 122 and through attenuator 91, to

5 While in the "ON" state, when a human (e.g. a hand) contacts touch panel 19, an electrical signal is provided to second gain circuit 14, in accordance with the LTS effect discussed above. A low impedance path is provided across the "Liu's Network" in
10 initialization and recovering reset circuit 15. As a result, capacitor C4 discharges through the low impedance path rapidly. Through diode gate 13, the low impedance path also interrupts the "ON" state feedback effect by shunting the trigger pulse in control
15 terminal 122 to common ground. Thus, at the next zero-crossing, when main semiconductor switch 1 becomes non-conducting, the absence of the trigger pulse places Liu Switch 300 in an "OFF" state, while the twin half-wave DC signal appearing across terminals 121 and 122
20 recharges capacitor C1. A fully charged capacitor C1 prevents a trigger pulse to be created at control terminal 122, and hence prevents main semiconductor switch 1 from triggered into a conducting mode, until the next contact at touch panel 17.

25 Thus, since Liu Switch 300 conducts no current
during the "OFF"-state, and is short-circuited during
the "ON" state (except at brief instances at zero-
crossings of the AC signal), Liu Switch 300 does not
require a power supply circuit for proper operation.
30 Consequently, a two-terminal network solid state switch
which operates in the same manner as a conventional
mechanical single-pole switch is realized.

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Fig. 7a: (a) Capacitor 4 is discharged through resistor R8 at a rate characterized by a ^{large} predetermined time constant; (b) Capacitor C4 ^{rapidly} is charged at a rate characterized by a small time constant (relative to the predetermined time constant above) when charged by a current from control terminal 122 through diode gate 13; and (c) Capacitor 4 ^{rapidly} is discharged at a rate characterized by a small time constant (relative to the predetermined time constant above) when discharged by the low impedance path of gain circuit 14.

The small time constant in charging through diode gate 13 (i.e., in ^b (c) above) allows the Liu's Network to serve as a dynamic energy absorber, to absorb shock, noise spike, and surge pulses which appear at control terminal 122. With this quality, ^{very} high stability in the "ON" and "OFF" states of Liu Switch 300 is achieved. The Liu's Network discharges through the low impedance path provided by second gain circuit 14 with a small time constant, so as to allow Liu Switch 300 to switch off quickly in response to contact at touch panel 19. In addition, the Liu's Network can achieve a desirable safety function. For example, in a conventional mechanical power switch, when the switch conducts (turns "ON"), a load is running (e.g., a heater, or a electric tool, a machine, etc.). However, during a power interruption, the load may be left in an operating mode when the power was interrupted. Thus, when power resumes at a later time unexpectedly, the load continues the interrupted operation. The resumption of power to a load left in an operating mode is the cause of accidents, causing fires, bodily injury and property damages.

The Liu's Network includes resistor (R8) to provide the predetermined discharge time constant. If the AC power is interrupted while Liu Switch 300 is in

the "ON" state, capacitor C4 discharges through resistor R8. The predetermined time constant maintains the charge on capacitor 4 for a predetermined time period. If the AC power recovers during this

5 predetermined time period (e.g., from a few to tens of seconds), capacitor 4 is unable to ^{completely} absorb the charging current of capacitor C1, thereby allowing a trigger pulse to reach terminal 84 (Figure 1) to trigger SCR1 and hence allowing Liu Switch 300 to resume its former

10 "ON" state. However, if the AC power recovers only after the predetermined time period has elapsed, capacitor C4 of the Liu's Network is substantially discharged through resistor R8, such that the charging pulse of capacitor C1 is shunted through diode gate 13

15 to capacitor ^C4. As a result, when AC power recovers after the predetermined period has elapsed, Liu Switch 300 recovers into the "OFF" state and remains stable in the "OFF" state indefinitely. Thus, the Liu's Network avoids load 2 resuming operation unexpectedly when

20 power recovers, thus avoiding accidents and harm.

When included in trigger and control circuit 200 (Fig. 1), "beep" circuit 21 indicates by sound successful switching of Liu Switch 300.

When included in trigger and control circuit 200,

25 overcurrent protection circuit 16 monitors the current in current detector 5, and provides an output control signal at input terminal 144 of gain circuit 14 when the current in current detector 5 exceeds a predetermined threshold. As discussed above, the

30 control signal at terminal 144 interrupts the "ON" state of Liu Switch 300.

When included in trigger and control circuit 200, optocoupler circuit 22 or 23 allow Liu Switch 300 to be used in a multipoint random control system. As shown

35 in Figure 1, optocoupler circuit 22 includes input

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terminals 223, 224 and 225, and provides output terminals 221, 222, 226 and 228. Terminal 225 is coupled to an external ground reference, terminals 221 and 226 are coupled respectively through terminals 121 and 122 to gain circuit 11, and terminals 222 and 228 are coupled respectively through terminals 141 and 142 (also common ground) to gain circuit 14. When a signal (AC or DC) appears across terminals 223 and 225, an optically isolated low impedance signal path is provided between terminals 221 and 226, thereby triggering the "ON" state of Liu Switch 300, in the manner explained above. Similarly, when a signal appears across terminals 224 and 225, an optically isolated low impedance path appears between terminals 222 and 228, thereby triggering the "OFF" state of Liu Switch 300. Using optical isolation, the output terminals 221, 222, 226 and 228 are each isolated by very high impedance from input terminals 223-225.

Optocoupler circuit 23 is similar to optocoupler circuit 22, except that an additional external ground signal 237 is provided so that highly isolated electrical paths are provided between terminals 223 and 235, 234 and 237, 231 and 236, and 232 and 238. When a signal (AC or DC) appears across terminals 233 and 235, an optically isolated low impedance signal path is provided between terminals 231 and 236, thereby triggering the "ON" state of Liu Switch 300, in the manner explained above. Similarly, when a signal appears across terminals 234 and 237, an optically isolated low impedance path appears between terminals 232 and 238, thereby triggering the "OFF" state of Liu Switch 300.

Several implementations of Liu Switch 300 are described below. To facilitate cross-referencing among the diagrams, reference numerals used in Figures 4-13

that correspond to reference numerals used in Figure 1 indicate elements or terminals identified in Figure 1 in these implementations.

Figure 4 shows one embodiment of the present invention in circuit 400, in which SCR controlled bridge rectifier 8 and main semiconductor switch 1 are implemented into a combined SCR-diode bridge circuit (1,8). As shown in Figure 4, a diode bridge BZ1 and an SCR1 realize the functions of SCR controlled bridge rectifier 8 and main semiconductor switch 1 of Figure 1. State memory and trigger circuit 12 is realized by series-connected resistor R3 and capacitor C1. Current-limiters 18 and 20 are realized by resistors R1 and R2. Gain circuits 11 and 14 are realized by NPN bipolar transistors T1 and T2. Attenuator 9 is realized by resistor R4.

During the "OFF" state, a rectified signal appears across terminals 83 and 85 and capacitor C1 is charged. When a human person contacts touch panel 17, a contact signal results from the LTS effect which turns on NPN transistor T1. Conducting transistor T1 discharges capacitor C1 and couples the twin half-wave DC signal at terminal 87 to terminal 92. Through resistor R4, the twin half-wave DC signal is provided to gate terminal G1 of SCR1, thus triggering SCR1 into conduction. Conducting SCR1 provides a short circuit between terminals 01 and 02 (i.e., main semiconductor switch 1), thus providing an AC signal across load 2, maintaining capacitor C1 in a discharged state, and incurring a voltage drop (V_{SAT-ON}) equal to the sum of two forward-biased drops in diode bridge BZ1 and the voltage drop across forward-biased SCR1 (i.e., 2.4-4.0 volts). When the AC signal crosses zero, SCR1 shuts off, so that capacitor C1 is charged by the next twin half-wave of the AC signal, thus providing a charging

current which triggers SCR1 back into conduction. Conducting SCR1 provides the AC signal across load 2 once again. This regenerating feedback process maintains Liu Switch 300 in the "ON" state. When a human contact touch panel 19, a contact signal from the LTS effect turns NPN transistor T2 into conduction, thus shorting terminal 92 to common ground, interrupting the feedback process described above, and setting Liu Switch 300 to the "OFF" state.

Figure 5 shows another embodiment of the present invention in circuit 500, which is substantially identical to circuit 400, except that PNP transistor T11 in circuit 500 replaces NPN transistor T1 of circuit 400. Otherwise, operation of circuit 500 is virtually identical to circuit 400 described above.

Circuits 400 and 500 have several disadvantages. First, a relatively large "ON" state voltage drop (2.4-4.0 volts) results in relatively large power dissipation in Liu Switch 300, requiring a heat sink for proper high-current operation, and reducing the voltage seen across load 2. Second, circuits 400 and 500 provide a Liu Switch which initializes in the "ON" state when coupled in the first instant to an AC signal source.

To minimize the "ON" state voltage drop (V_{SAT-ON}), semiconductor switch 1 can be implemented by a TRIAC or anti-parallel SCRs, as shown in Figures 6a and 6b. Figure 6a shows ~~on the~~ ^{one} embodiment of the present ~~Second~~ ^{invention} in circuit 600, in which main semiconductor switch 1 is implemented by a triode AC switch (TRIAC) 601. As shown in Figure 6a, terminals B13 and B14 (i.e., terminals 81 and 82 of Figure 1) of diode bridge BZ1 are coupled to gate terminal G and a second anode MT2 respectively. Current-limiting resistor 86 can be inserted in series between diode bridge BZ1 and TRIAC

601 at either terminals B13 and B14 to protect the gate terminal of TRIAC 601. During the "ON" state, the "ON" state voltage drop (V_{SAT-ON}) is between 0.8 volt to 1.6 volts. TRIAC 601 turns "OFF" at the AC signal's zero-crossing, after a high impedance is imposed across terminals G and MT2 (SCR1 non-conducting).

Figure 6b shows on the embodiment of the present invention in circuit 620, in which main semiconductor switch 1 is implemented by circuit 602 which is implemented by SCRs (i.e., SCR2 and SCR3) in an antiparallel configuration. Each SCR in circuit 602 is capable of carrying higher current than SCR1 of SCR controlled bridge rectifier 8. As shown in Figure 6a, terminals B13 and B14 (i.e., terminals 81 and 82 of Figure 1) of diode bridge BZ1 are coupled to gate terminals G3 and G2, respectively. As in circuit 600 of Figure 6a, current-limiting resistor 86 can be inserted in series between diode bridge BZ1 and antiparallel diodes SCR1 and SCR2 at either terminals B13 and B14 to protect the gate terminals G2 and G3. During the "ON" state, a trigger current is created between cathodes K3 and K2 of SCR3 and SCR2, respectively, which flows through the path formed by gate terminal G3 of SCR3, bridge rectifier BZ1, SCR1 and gate terminal G2 of SCR2. The trigger current alternately triggers SCR2 and SCR3 into conduction mode. During the "ON" state, the "ON" state voltage drop (V_{SAT-ON}) is thus approximately 1 volt. Main semiconductor switch 1 turns "OFF" at the AC signal's zero-crossing, after a high impedance is imposed across terminals G2 and G3 (SCR1 non-conducting), thereby setting SCR2 and SCR3 in non-conducting states.

By using power components (e.g., TRIAC 601, and SCR2, SCR3 of switch devises 602,) in circuits 600 and 620, the current that can be provided to load 2 is

easily expanded over the corresponding currents deliverable by circuits 400 and 500 of Figures 4 and 5. In addition, because of the low "ON" state voltage drop across Liu Switch 300, the power dissipation is also
5 diminished, as compared to circuits 400 and 500 discussed above, for the same current load.

Figure 7a shows another embodiment of the present invention in circuit 700, in which is provided a realization of initialization circuit and power
10 recovering reset circuit 15 and diode gate 13. Initialization circuit and power recovering reset circuit 15 and diode gate 13 is implemented by diode D3, resistor R8, and capacitors C4 and C4', referred below as "Liu's Network". In addition, circuit 700
15 implements attenuator 9 by a voltage divider formed by resistors R4 and R6. In circuit 700, gain circuit 14 is provided by a complementary cascaded amplifier including resistor R15, PNP transistor T3, and NPN transistor T2. SCR controlled bridge rectifier 8 and
20 main semiconductor switch 1 are implemented by a circuit similar to circuit 600, except that a bypass filter formed by capacitor C6 and resistor R7 is provided at the gate terminal of TRIAC 601. Gain circuit 11 and state memory and trigger circuit 12 are
25 provided as in circuit 400 above. Filter circuits 28 and 29 are each implemented by a capacitor (C2 or C3) connected in parallel with a diode (D1 or D2). In each of filter circuits 28 and 29, the diode (e.g., D1) is connected in an antiparallel fashion to the emitter
30 junction of the gain transistor (e.g., transistor T1). In this configuration, the diode performs at least three functions: (a) providing a negative path for to increase the distributive capacitive component (S_p) of the LTS effect; (b) protecting the emitter junction of
35 the gain transistor; and (c) detecting a peak in the

equivalent inductive signal source component (S_c) of the LTS effect.

In circuit 700, capacitor C4 provided in Liu's Network has a much larger capacitance than capacitor C1 of state memory and trigger circuit 12. In this embodiment, capacitor C4 can be implemented by an polarized electrolytic capacitor. Since a large electrolytic capacitor has a parasitic inductance, an unpolarized capacitor C4' is provided in Liu's Network to provide a fast response time to the Liu's Network.

Initially, i.e., when an AC power signal is first imposed across Liu Switch 300, both capacitors C4 and C1 are uncharged. As described above, capacitor C1 is fully charged within a very short period of time after the rectified signal across terminals 83 and 85 crosses zero. However, as capacitor C4 remains relatively uncharged, the charging current of capacitor C1 is shunted to charge capacitor C4 through forward-biased diode D3, so that a sufficient ^{triggering} ~~forward-biased~~ current pulse is not seen at input terminal 92 of attenuator 9, thus preventing triggering Liu Switch 300 into the "ON" state. During the "OFF" state of Liu Switch 300, no current thus flows in trigger and control circuit 200, as described above. (Leakage currents in gain circuits 11 and 14 are in the nano-ampere range, and thus negligible.) Resistor R8 maintains capacitor C4 in a substantially discharged state during the "OFF" state of Liu Switch 300. Thus, initialization circuit 15 provides additional stability in the "OFF" state, maintaining input terminal 122 of attenuator 9 no higher than one diode drop (i.e., about 0.7 volts) above the common ground, thereby preventing triggering of Liu Switch 300 by a momentary surge in the AC signal or by inadvertent momentary contact of touch panel 17.

As described above, when a person touches touch panel 17, capacitor C1 is discharged and the rectified signal is transmitted through the low impedance path through transistor T1 across terminals 121 and 122.

5 This signal, even though attenuated by attenuator 9, is sufficient to trigger SCR1 of SCR controlled bridge rectifier 8, which in turn, triggers main semiconductor switch 1 to a conducting state. As the "ON" state feedback process described above ~~is triggered to~~ maintain Liu Switch 300 in the "ON" state, a steady state is reached whereby capacitor C4 is maintained at a steady state voltage. At this time, if the AC power signal across lines 6 and 7 is suddenly interrupted, capacitor C4 discharges through resistor R8 according to the time constant determined by the capacitance and resistance values of capacitor C4 and resistor R8. Thus, by a judicious choice of these values, Liu Switch 300 can return to the "ON" state (i.e., an "ON" state memory is achieved), if the power resumes within the predetermined period of time. However, if the power resumed after the predetermined time period, capacitor C4 becomes discharged. Since discharged capacitor C4 can absorb the charging pulse of capacitor C1, as described above, a stable "OFF" state condition is created. Thus, Liu Switch 300 remains in the "OFF" state, until contact is made at touch panel 17 again.

Maintaining the "ON" state for a time period and then resetting to the "OFF" state thereafter can be exploited to provide a significant safety advantage (referred below as "Liu's function"). Many accidents with tragic consequences have been caused by electrical appliances or machinery left unattended and in the powered mode by a power outage. When the power recovers, these appliances or machinery resumes operation unattended, often leading to electrical appliance damages, accidents, fires or bodily injuries.

However, with Liu's Network, Liu's function allows the electrical appliances or machinery to resume operation from a power interruption (i.e., "latched-ON"), only if power recovers within a time period during which continued operation can proceed safely, but resets to the "OFF" state beyond such time period. Liu's function thus ^a~~provides uninterrupted operation during "brown out" of the power source.~~

Capacitor C2 or C2' of filter circuit 28, in conjunction with resistor R1 and the operator's equivalent impedance, forms a low-pass filter which eliminates high frequency electromagnetic interference from touch panel 17 and noise ^{in parallel}~~feedback~~ from gain circuit 11 due to a surge in the rectified signal.

Diode D1 serves three functions: (a) to provide an RF peak detector which enhances the inductive component (S_c) of the LTS effect; (b) to rectify the negative half-cycle signal current, thus improving the touch sensitivity of the touch panel towards the capacitive component (S_b) of the LTS effect; and (c) to protect the input terminals of the gain circuit. Capacitor C3 of filter circuit 29 performs a similar function as that performed by capacitor C2 or C2' described above.

In conjunction with resistor R5, resistor R7 and capacitor C6, which are connected in parallel at the gate terminal G of TRIAC 601, provide surge protection and suppress high frequency noise to gate terminal G of TRIAC 601 during operation. Further electromagnetic interference and noise filtering can be provided by series-connected EMI suppressers 3 and 3' (see Figure 1), which can be provided by many forms of low-pass filters, including LC circuits formed by solenoids with ferric alloy, ferrites cores with capacitors, or commercial monolithic EMI filters.

Figures 7b-7d show embodiments of the present invention in circuits 720, 740, and 760, each of which represents a modification of circuit 700 of Figure 7a. Circuit 720 includes a realization of filter circuit 28 by capacitor C2' and diode D1', and a realization of gain circuit 11 by PNP transistor T11. Circuit 740 of Figure 7c is substantially identical to circuit 700 of Figure 7a, except that antiparallel diodes SCR2 and SCR3 are provided for realizing main semiconductor switch 1, as in circuit 620 of Figure 6b. Circuit 760 of Figure 7d is substantially similar to circuit 720 of Figure 7b, except that antiparallel SCR2 and SCR3 are provided for realizing main semiconductor switch 1, as in circuit 620 of Figure 6b.

Figures 8a-8c show respectively circuits 800, 810 and 820 of a limiter (e.g., limiter 20). In circuit 800, a resistor R40 is provided. In circuit 810, a capacitor C42 is provided as a limiter. Capacitor C42 can be achieved by coating a dielectric or a resistive material on the metallic or conductor surface of the touch panel. In circuit 820, a capacitor C45 and a resistor R44 are provided in series.

Figure 9a shows a system block diagram of circuit 900, representing overcurrent signal processing circuit 16 of the present invention. Circuit 900 includes a current-to-voltage conversion device (AVC) 5, an AC-DC converter or a rectifier 904, an amplitude limiter with a regulator 905, a ripple filter 906, an auto-temperature compensation and overcurrent tripping value following temperature character circuit 907, a overcurrent tripping preset circuit 908, a threshold circuit, and an OR gate 903.

AVC 5 can be provided by a current transformer or a shunt element, or another type of current-voltage conversion devices. The current-side terminals of AVC

5 are connected in series with Liu Switch 300, load 2 and fuse 4 across AC power lines 6 and 7. The output signal of AVC 5, which is representative of the current in load 2 ("main current"), is coupled at to a AC-DC
5 converter or rectifier 904 (e.g., a half-wave rectifier, a full-wave rectifier, or a full wave bridge rectifier). The rectified signal is then regulated by regulator and amplitude limiter 905 and filtered by ripple filter 906. The resulting DC signal remains
10 representative of the main current. Temperature automatic compensation circuit 907 is provided to adjust the resulting DC signal according to temperature-sensitive current-tripping values that follow a set of characteristics curves (I_{or}-T curves).
15 The temperature-compensated DC signal is then attenuated by a voltage divider 908, and coupled to a threshold element set for a predetermined overcurrent tripping value. When an overcurrent condition occurs, an overcurrent signal is provided at terminal 144 to
20 "OR" gate 903 to trigger second gain circuit 14, to force Liu Switch 300 into the "OFF" state for protection. Backup input terminals 145 receive one or more actuating signal for turning off Liu Switch 300. Additional backup signal inputs, if needed for
25 performing automatic shut-off in additional protection functions, can be provided as additional input terminals of "OR" gate 903.

Figures 9b-9d show respectively realizations of three static overcurrent tripping circuits 910, 920 and
30 940 which can be used in Liu Switch 300. By providing overcurrent protection at Liu Switch 300 in the manner illustrated by circuits 910, 920 and 940, overcurrent protection is extended to a branch single pole switch at very low cost, thus enhances safety significantly
35 and avoiding the inconvenience of prior art centralized overcurrent protection schemes, which results in

multiple electrical circuits being affected by an overcurrent in a single electrical circuit.

In circuit 910, a small current transformer TF is provided as current detector 5. For current detection, rather than a current transformer, a shunt element or another current-voltage conversion element can also be used. In current transformer TF, the primary coil TF1 conducts the current in main semiconductor switch 1, while Secondary coil TF2 provides an AC current signal proportional to the current in coil TF1. Zener diode Z4, capacitor C7 and R12 form a voltage multiplier and half-wave rectifier. Zener diode Z4 regulates and limits the amplitude of resulting half-wave rectified signal, which is transmitted by ^{rectifier} ~~Zener diode~~ D10 to provide a DC voltage signal at terminal 902 representative of the current through main semiconductor switch 1. This DC voltage signal, which is ripple-filtered and attenuated by capacitor C8 and resistor network 907 (consisting of resistors R9 and R11, and temperature-sensitive resistors R10 and R10') is provided through silicon diode D5 as an input signal to gain circuit 14 of Liu Switch 300. By selecting appropriate resistive values for resistors in resistor network 907, an appropriate overcurrent tripping value for Liu Switch 300 can be selected.

When the overcurrent threshold is reached, resistor R14 and diode D4 (see Figure 13) provide a positive feedback which allows gain circuit 14 to rapidly set Liu Switch 300 into the "OFF" state. ~~Thus, circuit 910 enhances both sensitivity to overcurrent and sensitivity to touch at touch panel 19.~~

Significantly, silicon diode D5's forward-bias voltage drop has a negative temperature coefficient (i.e., diode D5's forward-bias voltage drop across its terminals decreases as temperature increases). Thus,

diode D5 provides a lower tripping threshold at a higher temperature. Temperature-sensitive devices (e.g., thermistors R10 and/or R10') provide dynamic characteristics of temperature-dependent overcurrent tripping points, and thus can be used to further compensate and fine-tune the tripping threshold in relation to temperature changes. In this manner, a temperature-compensated or adaptive overcurrent protection is achieved. When environmental temperature and the switch temperature changes, Liu Switch 300 can adapt to a new tripping value automatically. Thus, Liu Switch 300 provides an advanced protection function to protect human lives, the electrical network or the electric appliance in which Liu Switch 300 is installed, and Liu Switch 300 itself.

Of course, other thermal or temperature-sensitive elements can be used in Liu Switch 300 to achieve the same results discussed above.

Figure 9c shows circuit 920, which is a variation of circuit 910 of Figure 9a. In Figure 9c, circuit 920 uses a center-tapped secondary coil TF2 in current detector 5, and provides full-wave rectification by diodes D6 and D7. In circuit 920, the threshold element is provided by reverse-biased Zener diode D5 and a load resistor R13.

Figure 9d shows circuit 940, which is a variation of circuit 910 of Figure 9a. In Figure 9d, circuit 940 uses a diode bridge rectifier BZ2 to provide full-wave rectification of the voltage signal in Secondary coil TF2 of current detector 5. In circuit 940, the threshold element is provided by element TE1, which can be, for example, a PNP four-layer Shockley diode and a load resistor R13.

Figures 10a and 10b illustrate optional zero-crossing circuits 1000 and 1050 respectively. As shown

in Figure 10a, circuit 1000 includes a voltage divider formed by resistors R16 and R15, which are connected in series between terminals 83 and 85 (i.e., also coupled to the common ground of Liu Switch 300) of SCR controlled bridge rectifier 8, and NPN transistor T4, which base terminal is controlled by output ^{signal} voltage V_{b4} of the voltage divider. During the "OFF" state of Liu Switch 300, NPN transistor T4, when conducting, provides a low impedance path to short the trigger signal at the gate terminal G1 of SCR1 to common ground. Voltage V_{thres} , which is the minimum voltage above which NPN transistor T4 conducts, is thus a threshold voltage above which G1 is not triggered. Figure 10a also shows state memory and trigger circuit 12, attenuator 9, SCR controlled bridge rectifier 8 and main semiconductor switch 1 being implemented in the manner shown in 7a. Coupling diode D50 couples terminal 83 of SCR controlled bridge rectifier 8 to terminal 121 of trigger and control circuit 12. Figure 10c shows waveforms 1 and 2, being respectively the threshold voltage V_{thres} and the output impedance of transistor T4 at the gate terminal G1 of SCR1.

In circuit 1050 of Figure 10b, the voltage divider of resistors R15 and R16 of circuit 1000 is replaced by series-connected Zener diode Z1, light-emitter diode (LED) LED1 (optional) and a voltage divider formed by resistors R18 and R17. Because of the relatively constant voltage drop across Zener diode Z1, when conducting, a more precise zero-crossing threshold voltage V_{thres} can be selected from the voltage range of 9 volts to 19 volts. LED1 is included to allow Liu Switch 300 to be visible in the dark. This "night light" function, which requires less than 200 micro-amperes of current (still insufficient to trigger conduction in an implementation of main semiconductor switch 1 by a TRIAC or antiparallel SCRs), is

particularly useful when Liu Switch 300 is used as a light switch.

Figures 10a and 10b also show a simple, small, inexpensive and, in the steady state, current leakage-free implementation of "beep" circuit 21 by series connected Zener diode Z2 and a piezoelectric speaker element PE between node A and common ground. When node A rises from substantially common ground (i.e., the "ON" state of Liu Switch 300) to a high DC voltage (i.e., the "OFF" state of Liu Switch 300), a breakdown current passes through Z2 and rapidly charges the capacitive piezoelectric element PE, thereby generating an audible sound. This audible response can also be provided by coupling the Zener diode Z2 and piezoelectric element PE across any two nodes which experience a sudden change voltage. An audible "beep" sound is generated by piezoelectric speaker element PE when Liu Switch 300 switches. Thus, beep circuit 21 can be used to provide an audible sound response to the operator when Liu Switch 300 switches.

Figures 11a and 11b show implementations 1100 and 1150 of optocoupler circuits 22 and 23 coupled to Liu Switch 300 used as a multi-point random remote control solid state switch/relay, in the manner discussed above with respect to Figure 1. Using optical isolation, input control signals at terminals 223 and 224 (relative to common external ground terminal 225) of circuit 1100 are isolated from output signals across terminals 221 and 226 ("ON"-channel), and across terminals 222 and 228 ("OFF"-channel), by up to thousands of volts. Similarly, input control signals at terminals 233 and 234 of circuit 1150 (relative to two individual, highly isolated external ground terminals 235 and 237, respectively) are isolated from output signals across terminals 231 and 236 ("ON"-

channel), and across terminals 232 and 238 ("OFF" -
channel), by up to thousands of volts. Thus, signals
at terminal 223 and 224 and at external common ground
terminal 225 can be provided from a 3-wire bus 400 on
5 which any number of devices each capable of providing
the control signals can be connected. Figure 12a shows
3-wire control bus 400 used to provide multipoint
random remote control by external equipment to load 2a
through solid state switch 1200. Similarly, control
10 signals at terminals 233, 234 and at external ground
terminals 235 and 237 can be provided from a 4-wire bus
410 on which any number of devices each capable of
providing the control signals can be connected.
Figures 12b shows 4-wire control bus 410 used to
15 provide multipoint random remote control to the load 2b
through solid state switch 1201.

Figure 13 shows an embodiment of the present
invention in circuit 1300, which combines various
implementations of the various functional circuits of
20 Figure 1.

Liu Switch 300 has a built-in over-voltage
protection and thus does not require protection by a
protective device. This built-in over-voltage
protection can be illustrated, for example, by
25 reference to Figure 7a. During the "OFF" state, if an
over-voltage condition occurs (e.g., during a large
voltage surge in the AC signal), such that the
rectified twin half-wave DC signal across the collector
and emitter terminals of transistor T1 exceeds the
30 breakdown voltage of transistor T1, transistor T1
conducts. Conducting transistor T1 discharges
capacitor C1. The ^{current} ~~combined currents~~ of conducting
transistor T1 ~~and discharging capacitor C1~~ provide a
triggering pulse, which triggers SCR1 through
35 attenuator 9. Conducting SCR1 shorts diode bridge BZ1,

a

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which in turn triggers TRIAC 601 into a conducting state. Liu Switch 300 is thus switched into the "ON" state, so that the voltage across Liu Switch 300 drops to the voltage across conducting TRIAC 601. From this point, the regenerating feedback process described above sustains Liu Switch 300 in the "ON" state until Liu Switch 300 is switched into the "OFF" state by, for example, an external agent contacting touch panel 19. As the breakdown of transistor T1 and the conduction of TRIAC 601 occur within microseconds^{P8}, and also because the breakdown current of transistor T1 is limited by the resistance in attenuator 9, the over-voltage appearing across the terminals of Liu Switch 300 is too brief to cause damage to Liu Switch 300. Thus, Liu Switch 300 does not require protection by a protective device, even if the over-voltage condition persists in the AC signal. By eliminating the need for a protective device and by avoiding the cost of replacing damaged protective devices, Liu Switch 300 achieves substantial cost savings over the solid state switches of the prior art.

Thus, the present invention provides a switch which draws substantially no current during the "OFF" steady state, and requiring no power supply to operate the switch itself. In addition, the present invention provides a solid state switch that does not require a protective device for its over-voltage protection.

Numerous variations and modification within the scope of the present invention are possible. For example, gain circuits of Liu Switch 300 (e.g., gain circuits 11 and 14) may be implemented by another gain device, such as certain J-FETs, or MOS-FETs, Darlington bipolars, or another integrated circuit or operational amplifier. Main semiconductor switch device 1 can also be implemented by, for example, some IGBTs, GTOs, MCTs,

